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Final Report

A Comparison of Lyman α and HeI λ 10830
Line Structure and Variations
in Early-Type Star Atmospheres

NGR 33-219-002

Submitted by

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to

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(NASA-CR-154269) A COMPARISON OF LYMAN
ALPHA AND HeI LAMBDA 10830 LINE STRUCTURE
AND VARIATIONS IN EARLY-TYPE STAR
ATMOSPHERES Final Report (State Univ. of
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Introduction

The profile behavior and form of light element resonance lines such as HI Lyman α , HeI 10830 Å, OI 1302-6 and OI 7774/8446 provide important diagnostic information concerning the atmospheric structure of early-type stars. Because Ly α and 10830 occur in widely separated spectral regions, the constraints upon model atmosphere calculations these two lines provide are more severe than usually available, particularly when non-LTE effects are included. With this end in mind, the Vaughn pressure-scanned Fabry-Perot interferometer was modified for use as a narrow-band, single-order, near-infrared scanner. The modified device has been used on the 0.6 m telescope at the University of Rochester, C.E.K. Mees Observatory and most recently on the Kitt Peak National Observatory 0.9 m telescopes. The Copernicus Space Telescope of The Princeton University Observatory has been used to obtain Ly α as well as OI 1302-6 profiles in a number of stars in the 10830 observing program. In addition to the interest in the 10830 Å line as an indicator of stellar non-LTE conditions, the recently discovered correlation between solar 10830 Å emission and the lack of solar coronal X-ray emission (coronal holes) has sparked renewed discussion of resonance line formation mechanisms in turbulent regimes.

Starting in September 1977, the principal investigator will be spending a one-year sabbatical at the Goddard Space Flight Center as a NRC-NAS Senior Research Associate. During this time, effort will be concentrated upon final 10830 and UV line profile reductions, qualitative interpretations, and an initial start on quantitative aspects of an eventual model atmosphere analysis.

The Observational Programs - Current Status

To date approximately 80 scans of 10830 have been obtained in 50 "northern" OBA stars with a photometric accuracy of between 3% and 10% depending on the apparent infrared magnitudes of the stars. A wide variety of objects have now been surveyed between 05-A2 in spectral type and I-V in luminosity class. In addition to normal standard stars, particular attention has been paid to stars likely to show time-variations including

- (a) Supergiants
- (b) Be and Shell stars
- (c) Bp and Ap stars
- (d) Eclipsing and spectroscopic binaries.

Although the early 10830 observations were plagued by weather and instrumentation problems, since moving the instrumentation to Kitt Peak satisfactory results have been obtained. While the FW-118 sensitivity is not as high as when Vaughn used it, storage in the dry Arizona climate has produced an unexpected ten-fold reduction in the tube noise level. It was therefore possible to attempt moderate precision (3-5% counting accuracy) surveys of a number of stars not a part of the originally proposed program.

Some exploratory work on the HI Paschen 10938 and OI 7774/8443 lines has also been performed using the F-P interferometer. Limited wide-band narrow-band interference filter photometry of 10830 and 10938 has been obtained for a limited number of the brighter program stars. A photographic survey of the OI 7774/8443 lines in the program stars of later spectral types (B3-A5) and using I-N hypersensitized plates is continuing with the C.E.K. Mees 0.6 m telescope (University of Rochester). When the initial photographic survey is complete, observing time to obtain high accuracy Fabry-Perot profiles will be requested, probably at Kitt Peak.

As a summary of the current status of the observation program, Table I lists (according to right ascension) all stars for which raw F-P scans have been obtained with notes concerning the availability of Copernicus telescope UV scans. For stars for which Copernicus scans are either poor or not available, a comment in square brackets is given. Copernicus time for γ Ori, 13 Mon, θ Pup, β UMa, and α CrB during late 1977 and 1978 is being requested.

In Table II, the stars presented in Table I are rearranged by special interest group. Those stars on the original observational list are indicated in Table II by a single asterisk. Of the original stars only three stars do not have satisfactory 10830 profiles available-- α Col, σ Sco, and γ Peg. This is counterbalanced by the fact that twenty-four additional stars were obtained. Unfortunately, because of the instrumentation problems to be discussed later, the profiles deconvolution has become a more time-consuming task than originally envisioned and so even "quick-look" reductions are available only for about 30% of the stars listed.

Instrumentation - Current Status

In spite of early instrumentation setbacks, it has now become almost routine to obtain raw F-P profiles at 10830 Å. Our original goal of real-time data reduction, however, was not realized. In particular, the use of CO₂ as the scanning gas introduces reduction complications of non-linear scanning intervals as well as zero point drifts due to CO₂ condensation in the F-P chamber. Instrumental modifications which will alleviate the CO₂ condensation problem are currently being incorporated into the F-P design.

Table I

Right Ascension List of Stars for Which 10830 Profiles Have Been Obtained Using the Vaughn Fabry-Perot Interferometer (by June 1977) under NASA Grant NGR 33-219-002.

α And	B9p (Mn)	1 scan	SB, $\phi = .96$	Copernicus Star
γ Cas	B0IV:e	2 scans		Copernicus Star
ϕ Per	B0ne: shell	1 scan	SB, $\phi = .23$	Copernicus Star
β Per	B8V	6 scans	EB, $\phi = \text{various}$	Copernicus Star
ψ Per	B5ne: shell	1 scan		Copernicus Star
η Tau	B7III	1 scan		Copernicus Star
ζ Per	B1Iab	1 scan		Copernicus Star
ϵ Aur	A8Ia/F0Iap	1 scan		[Too Faint for Copernicus]
β Ori	B8Ia	3 scans		Copernicus Star
γ Ori	B2III	1 scan		[No U2 scans?]
β Tau	B7III	1 scan		Copernicus Star (DDM)
λ Ori	O8, Oe5	1-1/2 scans		Copernicus Star
θ Ori	O6	1 scan		[Multiple, Poor Guiding]
ζ Tau	B2IVp (*)	2 scans ($\phi = .74$)		Copernicus Star
δ Ori	O9.5III	1 scan		Copernicus Star
τ Ori	O9III	1 scan		Copernicus Star
ϵ Ori	B0Ia	1-1/2 scans		Copernicus Star
ζ Ori	O9.5Ia	1-1/2 scans		Copernicus Star
κ Ori	B0.5Ia (*)	1-1/2 scans		Copernicus Star
θ Aur	B9.5pv(Si)	1 scan		Copernicus Star
17 Lep	Aeq (shell)	1 scan		[Too Faint for Copernicus?]
β CMa	B1III-III	1-1/2 scans		Copernicus Star
β Mon	B3Ve, B4V	1 scan		[Multiple, Poor Guiding]
13 Mon	A0Ib	1 scan		[Copernicus Time Requested]
γ Gem	A0IV	1 scan		Copernicus Star (DDM)
α CMa A&B	A1V + wd	1 scan		Copernicus Star
ϵ CMa	B2II	1 scan		Copernicus Star
σ^2 CMa	B3Ia	1-1/2 scans		Copernicus Star
η CMa	B5Ia	1 scan		Copernicus Star
β CMi	B7V (*)	1 scan		Copernicus Star (DDM)
σ Pup	B0pe	1 scan		[Copernicus Time Requested]
α Leo	B7V	2 scans		Copernicus Star
η Leo	A0Ib	1 scan		[U2 selected lines]

Table I (continued)

β UMa	A1V	1 scan	[Copernicus Time Requested]
ρ Leo	B1Ib	1 scan	Copernicus Star
γ UMa	A0Vn	1 scan	Copernicus Star (DDM)
γ Crv	B8III	1 scan	Copernicus Star (DDM)
δ Crv	B9.5V	1 scan	Copernicus Star (DDM)
κ Dra	B7Ve (*)	1 scan	Copernicus Star
ϵ UMa	A0p (Cr)	3 scans	Copernicus Star
α^2 CVn	Ap	2 scans	Copernicus Star
α Vir	B1V	2 scans	Copernicus Star (DDM)
η UMa	B3V	1 scan	Copernicus Star
β Lib	B8V	1 scan	Copernicus Star
α CrB	A0V	1 scan	[Copernicus Time Requested]
ζ Dra	B6III	1 scan	Copernicus Star
α Lyr	A0V	2 scans	Copernicus Star
P Cyg	B1e	1 scan	Copernicus Star
δ Cyg	B9.5III	1 scan	Copernicus Star (DDM)
α Cyg	A2Ia	2 scans	Copernicus Star

*Spectral classification may be incorrect.

Table II

F-P 10830 Stars Arranged According to Special Interest or Spectral Type Groups

Supergiants

ζ Per	B1Iab	*κ Ori	B0.5Ia (**)	ο ² CMa	B3Ia
ε Aur	A8Ia/F0Iap	*ε Ori	B0Ia	η CMa	B5Ia
*β Ori	B8Ia	13 Mon	A0Ib	η Leo	A0Ib
*ζ Ori	O9.5Ia	*α Cyg	A2Ib	ρ Leo	B1Ib

Early Be/Shell Stars

*γ Cas	B0IV:e	β Mon	B3V
φ Per	B0ne: shell	ο Pup	B0pe
ψ Per	B5ne: shell	ρ Cyg	B1e
*ζ Tau	B2IVp (**)		

Late B Peculiar Stars

*α And	B9p (Mn)	κ Dra	B7Ve (**)
θ Aur	B9.5p (Si)	*ε UMa	A0p (Cr)
17 Lep	Aeq (shell)	α ² CVn	Ap

OB Stars

γ Ori	B2III	i Ori	O9III	ε CMa	B2II
λ Ori	O8, Oe5	*α Vir	B1V		
θ Ori	O6	η UMa	B3V		
*δ Ori	O9.5III	*β CMa	B1II-III		

Late B Stars

*β Per	B8V	*α CMa	A1V	*γ UMa	A0V
*η Tau	B7III	*β CMi	B7V (***)	*γ CrV	B8III
*β Tau	B7III	*α Leo	B7V	*δ CrV	B9.5V
*γ Gem	A0IV	β UMa	A1V	*β Lib	B8V
α CrB	A0V	*α Lyr	A0V	ζ Dra	B6III
				*δ Cyg	B9.5III

Notes:

- * Original program star
- ** Classification in doubt or controversial
- *** May be a Be star

These modifications should eliminate all zero-point drifts from future F-P 10830 observations. They, however, cannot alter the reduction problems already present in the data now on hand. The F-P is currently being stored at Kitt Peak in case additional observing time becomes available. No plans exist for use elsewhere as appropriate shipping funds are not available.

Theoretical Analyses - Current Status

Initial modifications of computer codes of standard LTE model atmosphere programs for running on the University of Buffalo CYBER computer system have been made with the kind cooperation of Dr. H. van Horn of the University of Rochester and Dr. L. Auer of NCAR, Boulder, Colorado. Work on non-LTE problems will commence after LTE predictions have been generated.

Future Goals and Aims

During 1977-78, the principal investigator will be a NAS-NRC research associate at the Goddard Space Flight Center where work on the available 10830 and Lyman α profiles will, hopefully, be completed. Therefore no follow-on proposal to this grant will be possible until the fall of 1978. Present plans call for semi-qualitative discussions of the available observational material to be published during 1977-78. The time-scale required before quantitative theoretical discussions can be attempted is difficult to predict, but 3-5 years is not unrealistic. Thus while the formal financial NASA support terminates with this report, work on the 10830 profile and related problems will continue. It seems appropriate to conclude this final report with a summary of intended future extensions of the grant work.

A. Observational Tasks (1977-80)

- (a) During 1978-80 an effort will be made to complete the 10830 survey of all OBA stars up to $m_{IR} = 3^m.5$ both northern and southern. NASA or NSF support will be solicited.
- (b) During 1977-78, Copernicus UV observations will be proposed and hopefully completed using travel available as an NRC-Senior Associate. Observing proposals for guest-investigator status on the I.U.E. will be generated for the 1978-80 period.
- (c) Completion of the photographic OI 7774/8443 survey will be attempted during 1977-78 by D. Kelly of SUNY-Geneseo. A photoelectric survey will be planned for 1978-80 once the results of the photographic survey are available.

B. Data Reduction and Publication

During 1977-78, final deconvolved F-P 10830 Å profiles will be constructed for all available data. It remains to be determined whether a single atlas or several specialized group atlases will be produced. Final UV profiles of Copernicus data will also be completed.

C. Theoretical Calculations and Model Atmospheres

In preparation for line profile calculations on the University of Buffalo CYBER system, the Computer Center staff of SUNY-Geneseo will modify as necessary several existing atmosphere programs including those made available by the University of Rochester and the Goddard Space Flight Center. By 1978, some non-LTE work may begin, either at Goddard or upon return to Geneseo.

Summary

The preliminary conclusions given in the AAS abstract accurately describe the present status of the work. Some additional details are given in the progress report dated January 1977. Time has not permitted generating a similar description here for the profiles obtained in March 1977. It can be stated, however, that the interactions of doppler-shifted $10830 \text{ \AA}$ components and the SiI $10827 \text{ \AA}$ appear to be real and represent a serious complication that was not previously suspected. Even when there is no apparent $10830/10827$ interaction, profile changes on time scales short compared to the scan time are so serious that for some stars, it may be impossible to ever obtain a satisfactory final deconvolved contour. Although progress was much delayed by instrumentation difficulties, it is felt that the available 10830 raw data certainly satisfies the originally stated objectives of the ground-based part of the grant proposal. The concentration on the 10830 problem seemed obligatory and timely. Hence progress on the OI lines and the model atmosphere calculations was very limited. It is hoped that the NAS-NRC Senior Associateship will enable the principal investigator time to complete the data analysis as well as initiate several publications on the 10830 problem. In this sense, the 1977-78 period is envisioned as a period of "no-cost" extension of the present work. Copies of the publications produced while on the Goddard staff will be transmitted to NASA headquarters to be kept on file as appendices to this final report.

Publications Under This Grant

Meisel, D. D., Saunders, B. A., and Kelly, D. R. 1977, "Helium 10830 in Early-Type Stars," Bull. Am. Astron. Soc. 9, 366.

Feeney, M. T. 1976, "A Study of Ly α and OI λ 1306 Line Profiles in Early Type Stars," M.A. Physics Thesis, SUNY-Geneseo.

Meisel, D. D. and Berg, R. A. 1975, "Helium λ 10830 in Alpha Virginis A and B," Ap. J. 198, 551.

Meisel, D. D. and Berg, R. A. 1974, "High Resolution Spectrophotometry of Selected Features in the 1.1 μ m Spectrum of Comet Kohoutek (1973f)," Icarus 23, 454.

The JSC/SRL features a 40-cm aplanatic reflector with a dual star-tracking system and a detector system consisting of an echelle spectrograph and an SEC Vidicon. The spectrum longward of about 2800 Å exhibits numerous emission features attributable to the extended atmospheres of this late-type supergiant (M2 Iab). Of particular interest is the asymmetry in one of the Mg II resonance doublet emissions (2795.523 and 2802.698 Å). As reported earlier (Kondo et al., 1972, *Ap. J.*, 176, 153; Kondo, Morgan and Modisette, 1975, *Ap. J.*, 196, L125; and Bernat and Lambert, 1976, *Ap. J.*, 204, 830), the 2795 emission is asymmetric due to the selective absorption occurring in the cool shell surrounding Betelgeuse. Modisette, Nicholas and Kondo (1973, *Ap. J.*, 186, 219) attributed the asymmetry to the selective absorption by Fe I (2795.006 Å) while Bernat and Lambert attributed it to Mn I (2794.817 Å) and Fe I. In the current results we are able to delineate the absorption due to the neutral metal as a distinct absorption feature rather than merely as asymmetry in the Mg II 2795 emission. The central wavelength of this absorption feature tends to favor Fe I.

33.08.05 Low excitation early-type emissions and late-type absorptions in the spectrum of RX Puppis M. KLUTZ, O. SIMONETT, and J. P. SWINGS, *Univ. Liège, Belgium*. The high excitation emission lines typical of a true symbiotic star that were reported by P. Swings and Struve in 1941 are now absent. Spectrograms obtained in 1972, 1975, 1976 show essentially emission lines of H (with rapidly variable P Cygni structure) and permitted and forbidden emissions of singly ionized metals, mainly Fe II. In addition sharp absorptions are detected in 1977 on 20 Å mm⁻¹ spectra that are now obtainable because of the increase in brightness of RX Puppis. An analysis of these new data will be presented.

33.09.05 Balmer Lines Near the Series Limit in A-Type Spectra. R. J. PANEK, *Penn State U.* For seven bright, A-type stars, the absolute flux at 3600-4200 Å has been measured with 10 Å resolution, using a photoelectric scanning spectrometer. An attempt was made to directly determine the instrumental line profile. The program stars are well suited to comparison with models because they have a well determined angular diameter and empirical

effective temperature. The effective temperatures range from 8000-10000°K, and the surface gravity from log g = 3.3-4.5. New synthetic spectra in this wavelength interval have been computed using recently published, line blanketed model atmospheres. These calculations explicitly include the detailed line absorption profiles of many Balmer lines. The quasistatic approximation which is used for the Stark broadening should be accurate for these high series lines. The theoretical spectra were convolved with the instrumental profile for direct comparison with the observations. Each star is compared to a model on the basis of effective temperature. The model continuum fluxes for the hotter stars tend to be faint near 4000 Å. After allowance for the absorption of metal lines not included in the theoretical spectra, the converging Balmer lines are quantitatively seen to be well reproduced by these theoretical spectra.

33.10.05 Moderate Resolution Ultraviolet Rocket Observations 912-3100 Å of Seven Early-Type Stars. W. H. BRUNE, G. H. MOUNT, and P. D. FELDMAN, *The Johns Hopkins University*. - Ultraviolet spectra in the wavelength region 912 to 3100 Å of seven hot stars were obtained at 15 Å resolution with three scanning spectrometers. The spectrometers were aboard an Aerobee 170 rocket, which was launched from Australia on February 17, 1977, at 13:30 U.T. Stellar fluxes have been determined with high photometric accuracy. Stars observed were γ Vel (C 7), ζ Pup (O5), α Eri (B5 IV), β Cen (B1 II), α Vir (B1 V), α CMa (A1 V). The data will be presented and compared with the predictions of stellar model-atmosphere calculations. Possible detection of the white dwarf companion of Sirius will also be discussed. This work was supported by NASA under grant NGR 21-001-001.

33.11.05 Helium 10830 in Early-Type Stars I. D. D. MEISSEL,† B. A. SAUNDERS, and D. R. KELLY, *SUNY-Geneseo*. - Fabry-Perot interferometric profiles for fifty of the brighter early-type stars including supergiants, eclipsing binaries, Bp and Ap stars, Be and shell stars, and variable stars have been obtained using the Kitt Peak 0.9 m telescopes and the C.E.K. Mees 0.6 m telescope. Results for δ Persei (Algol) just before primary and secondary eclipses show strong emission profiles lasting about 0.1 phase. An absorption line was seen during secondary eclipse. A sampling of bright supergiant stars (O9-A2) show time-variable, complicated absorption/emission profiles similar in many respects to those obtained for the Be/shell stars. Observations to complete at least one profile of all 5 stars brighter than m_v=4 north of δ=-25° will continue. Ultimately these

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10830 profiles will be compared to Ly α and OI 1306 profiles in the same stars.

This work was supported by NASA Grant NGR 33-219-002.

*Associate C.E.K. Mees Observatory, University of Rochester.

†Visiting Astronomer Kitt Peak National Observatory, Operated by Associated Universities for Research in Astronomy and Guest Investigator, Copernicus Telescope, Princeton University Observatory.

33.12.05 The Infrared Eclipse of V444 Cygni and the Structure of Wolf-Rayet Stars. L. Hartmann, CEA - Observations of the eclipse of the W5 component of the V444 Cyg system at 2.2 and 3.4 μ confirm the idea that free-free emission is the source of the infrared excess. The optical and infrared eclipses have been investigated with a stellar atmospheres program; the results support the model of Hartmann and Cassinelli (1977, Ap. J., in press) of the W5 star HD 50896, in which the optical photosphere is not accelerating. The uniqueness of the model is discussed, along with implications for theories of radiatively driven winds.

33.13.05 The absolute spectral energy distribution of η UMa (B3V) in the ultraviolet and the visual. G. J. STRONGYILIS, UNIV. OF MARYLAND and R. C. BOHLIN NASA/GSFC. The absolute spectral energy distribution of the star η UMa (B3V) has been observed in the ultraviolet with the OAC-2, TD1-52/68 and Apollo 17 experiments, and by Bohlin and Stacher with rockets. This basic collection of observations shows a maximum scatter of 35% near 1500 $\text{\AA}$. Longward of 1700 $\text{\AA}$ these data have a typical scatter of only $\pm 5\%$. A new model atmosphere from Kurucz with $T = 17000$ K and $\log g = 4.00$ agrees well with the collected ultraviolet observations and the visual flux distributions on the Hayes andatham scale. The unreddened model is within 20% of all observations in the 1200 to 1700 $\text{\AA}$ region and within 5% longward of 1700 $\text{\AA}$. A slightly modified version of the model that accounts for the line blocking observed by the Copernicus satellite is proposed as the absolute flux standard in the ultraviolet and the visual. This standard can be used for in-flight calibrations and to derive revised absolute calibrations for any experiment, thus placing all absolute flux measurements on a common scale. Near the peak of the interstellar extinction curve at 2160 $\text{\AA}$ there is a maximum of 5% difference between the model and the observations.

In order to address the question of whether the rapid rotation of η UMa ($v \sin i = 216 \text{ km s}^{-1}$) has a significant effect on the shape of the ultraviolet continuum, the TD1-52/68 flux distributions of η UMa and the slow rotator i Her (B3IV, $v \sin i = 8 \text{ km s}^{-1}$) were compared in the 1400 to

2500 $\text{\AA}$ region. The observed differences in shape can be explained to 2% by a reasonable amount of extinction with $E(B-V) = 0.02$, plus a small difference in temperature of $\Delta T = 1400$ K. Thus, the non-rotating model that fits best the observations of η UMa in the ultraviolet has an error in the proposed flux of less than 2%, attributable to rotational effects.

33.14.05 The Superposition of Layers Method Applied to Emitting Atmospheres. R. W. WHITAKER and H. G. HORAK, University of California, Los Alamos Scientific Laboratory. - The superposition of layers method is applied to plane-parallel atmospheres with given source distributions. The procedure is based on the direct application of the principles of invariance combined with required symmetry relations.* The method is discussed for source distributions that are polynomial or exponential functions of optical depth. Numerical results are presented.

*The Transfer of Radiation by an Emitting Atmosphere.

II. H. Horak and C. Lundquist, Ap. J. 119, 42, (1954).

IV. C. Lundquist and H. Horak, Ap. J. 121, 175, (1955).

WEDNESDAY, 15 JUNE

Session 34: Room 500, General Classroom Building

1400-1730

PS.01.03 Energetics of Newly Formed Coronal Loop Systems. G. W. PNEUMAN, NCAR. - Following solar flares and major coronal transient events, newly formed magnetic loops are often observed in x-rays, XUV lines, and in H α . The loop system rises into the corona from the base at velocities of the order of 10 km/sec. This upward motion does not reflect the expansion of single loops but, rather, the formation of new loops at successively greater heights. According to the theory of Kopp and Pneuman, this phenomenon is the result of the reconnection of field lines previously torn open by the force of the transient event, i.e., the relaxation of the magnetic field to its original closed equilibrium configuration prior to the flare. One important observed property of these systems is that very high temperature material ($T \sim 7 \times 10^6$ K) is seen at the top of the most recently formed loops - indicating a large energy input at this location. Since the closed loop geometry following reconnection possesses a lower energy content than that of the open geometry immediately following

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